AD NO. ____________________________
DTC PROJECT NO. 8-CO-160-UXO-016
REPORT NO. ATC-9404

SHALLOW WATER

UXO TECHNOLOGY DEMONSTRATION SITE

SCORING RECORD NO. 7

SITE LOCATION:
U.S. ARMY ABERDEEN PROVING GROUND

DEMONSTRATOR:
AMEC EARTH AND ENVIRONMENTAL, INC.
800 MARQUETTE AVE, SUITE 1200
MINNEAPOLIS, MN 55402

TECHNOLOGY TYPE/PLATFORM:
3DGEO/SLED

PREPARED BY:
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ABERDEEN PROVING GROUND, MD 21005-5059

MAY 2007

Prepared for:
U.S. ARMY ENVIRONMENTAL COMMAND
ABERDEEN PROVING GROUND, MD 21010-5401

U.S. ARMY DEVELOPMENTAL TEST COMMAND
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CSTE-DTC-AT-SL-E

MEMORANDUM FOR RECORD

SUBJECT: Operations Security (OPSEC) Review of Paper/Presentation

1. The attached record entitled "The Shallow Water UXO Technology Demonstration Site Scoring Record No. 7" dated May 2007 is provided for review for public disclosure in accordance with AR 530-1 as supplemented. The scoring record is proposed for public release via the internet.

2. I, the undersigned, am aware of the intelligence interest in open source publications and in the subject matter of the information I have reviewed for intelligence purposes. I certify that I have sufficient technical expertise in the subject matter of this report and that, to the best of my knowledge, the net benefit of this public release outweighs the potential damage to the essential secrecy of all related ATC, DTC, ATEC, Army or other DOD programs of which I am aware.

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None.

14. ABSTRACT

This report documents the efforts of AMEC Earth and Environmental, Inc., to detect and discriminate inert unexploded ordnance (UXO) using an underwater towed sensor array designed by 3DGeophysics. Testing was conducted at ATC, Standardized Shallow Water UXO Technology Demonstration Site. A description of the tested system and an estimate of survey costs along with the analysis of the system performance are provided.

15. SUBJECT TERMS
AMEC, 3DGeophysics, UXO Standardized Technology Demonstration Site, Shallow Water, Towed Sensor Array, MEC

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SECTION 1. GENERAL INFORMATION

1.1 BACKGROUND

Technologies under development for the detection and discrimination of munitions and explosives of concern (MEC), i.e., unexploded ordnance (UXO) and discarded military munitions (DMM), require independent testing so their performance can be characterized. To that end, the U.S. Army Aberdeen Test Center (ATC) located at Aberdeen Proving Ground (APG), Maryland, has developed a Standardized Shallow Water Test Site. This site provides a controlled environment containing varying water depths, multiple types of ordnance and clutter items, as well as navigational and detection challenges. Testing at this site is independently administered and analyzed by the government for the purposes of characterizing technologies, tracking performance during system development, and comparing the performance and costs of different systems.

The Standardized UXO Technology Demonstration Site Program is a multi-agency program spearheaded by the U.S. Army Environmental Command (USAEC). ATC and the U.S. Army Corps of Engineers Engineering, Research and Development Center (ERDC) provide programmatic support. The Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP), and the Army Environmental Quality Technology Program (EQT) provided funding and support for this program.

1.2 OBJECTIVE

The objective of the Shallow Water Standardized UXO Technology Demonstration Site is to evaluate the detection and discrimination capabilities of existing and emerging technologies and systems in a shallow water environment. Specifically:

a. To determine the demonstrator’s ability to survey a shallow water area, analyze the survey data, and provide a prioritized “Target List” with associated confidence levels in a timely manner.

b. To determine both the detection and discrimination effectiveness under realistic scenarios that varies ordnance, clutter, and bathymetric conditions.

c. To determine cost, time, and manpower requirements needed to operate the technology.

1.3 CRITERIA

The scoring criteria specified in the Environmental Quality Technology - Operational Requirements Document (EQT-ORD) (app D, ref 1) for: A(1.6.a): UXO Screening, Detection and Discrimination document are presented in Table 1-1. Very little information was available on the capabilities of shallow water detection systems when these criteria were developed. However, they were used in the design of the test site, and the five metrics were used to measure system performance in this report.

TABLE 1-1. SCORING CRITERIA

Metric	Threshold	Objective
Detection	80% ordnance items buried to 1 foot and under 8 feet (2.4 m) of water at a standardized site detected	95% ordnance items buried to 4 feet and under 8 feet (2.4 m) of water at a standardized site detected
Discrimination	Rejection rate of 50% of emplaced non-UXO clutter at a standardized site with a maximum false negative rate of 10%	Rejection rate of 90% of emplaced non-UXO clutter at a standardized site with a maximum false negative rate of 0.5%
Reacquisition	Reacquire within 1 meter	Reacquire within 0.5 meter
Cost rate	$4000 per acre	$2000 per acre
Production rate	5 acres per day	50 acres per day

The ATC shallow water site is designed to evaluate the threshold-detection level of a range of ordnance at the 1-foot + 8-foot requirement. Limited information is available at the objective-detection level. All other measured results in this test were evaluated against both criteria levels.

1.4 APG SHALLOW WATER SITE INFORMATION

1.4.1 Location

The Aberdeen Area of APG is located in the northeast portion of Maryland on the western shore of the Chesapeake Bay in Harford County. The Shallow Water Test Site is located within a controlled range area of APG.

1.4.2 Soil Type

The area chosen for the shallow water test site was known as Cell No. 3 in a dredge-spoil field. The cell bottom is composed primarily of sediment removed from the Bush River. This is a freshwater site.

1.4.3 Test Areas

a. The test site contains five areas: calibration grid, blind test grid, littoral, open water, and deeper water. Additional detail on each area is presented in Table 1-2. A schematic of the calibration lanes is shown in Figure 1.

TABLE 1-2. TEST AREAS

Area	Description
Calibration grid	The calibration area contains 15 projectiles, 3 each 40, 60, 81, 105, and 155 mm. One of each projectile type is buried at the projectile diameter to depth ratio shown in Figure 1. This area is designed to provide the user with a sensor library of detection responses for the emplaced targets and an understanding of their resistivity prior to entering the blind test fields. Two "clutter-cloud" target scenarios have been constructed adjacent to this area (fig. 1).
Blind grid	The blind grid contains 644 detection opportunities. Each grid cell is 2 by 2 m^2. At the center of each cell is either an ordnance item, clutter, or nothing. Surrounding the blind grid on three sides are 3.6-kg (8-lb) shotputs, buried 0.3 meter deep in the sediment. The shotputs can be used as a navigational/Global Positioning System (GPS) check. The GPS coordinates for the center of each grid and the shotput locations are provided to the vendor prior to testing.
Littoral	This is a sloping area on one side of the pond with vegetation growing into the water line. Water depth ranges from 0.3 to 1.8 meters. It contains a variety of navigational and detection challenges.
Open water	The open water scenario contains a variety of navigational, detection, and discrimination challenges. Water depth varies from 1.8 to 3.4 meters.
Deeper water	The water depth in this area varies between 3.4 and 4.3 meters.

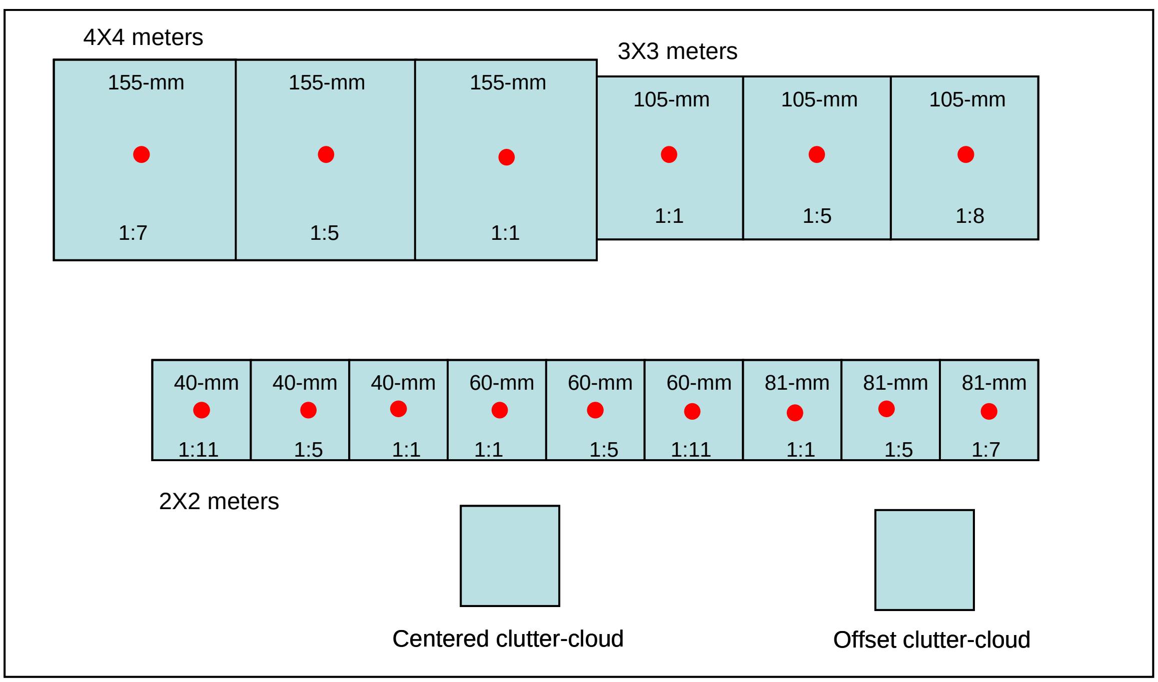

Figure 1. Schematic of the calibration grid.

b. The water depth at this facility during testing is maintained such that the calibration and blind grid areas meet the 2.4-meter (8-ft) detection criterion specified in section 1.3. The test site is approximately 2.8 hectares (6.9 acres) in size.

1.5 GROUND TRUTH TARGETS

The ground truth is composed of both inert ordnance and clutter items. The inert ordnance items are listed in Table 1-3. All items were located in storage sites at APG. The items have not been fired or degaussed.

Clutter items fit into one of three categories: ferrous, nonferrous, and mixed metals. The ferrous and nonferrous items are further divided into the three weight zones as presented in Table 1-4, and distributed throughout all test areas. Most of this clutter is composed of ordnance components; however, industrial scrap metal and cultural items are present as well. The mixed-metals clutter is composed of scrap ordnance items or fragments that have both a ferrous and nonferrous component and could reasonably be encountered in a range area. The mixed-metals clutter was placed in the open water area only.

TABLE 1-3. INERT ORDNANCE TARGETS

Description	Length, mm	Diameter, mm	Aspect Ratio, W/L	Weight, g
40-mm L70 projectile	208	40	0.1923	965
60-mm mortar M49A2	185	60	0.3243	975
81-mm mortar M374	528	81	0.1534	3,969
81-mm mortar M821	510	81	0.1588	3,338
105-mm projectile M1	445	105	0.2360	13,834
155-mm M107 projectile	684	155	0.2266	41,731
8-in. M104/106	856	203	0.2371	89,811

L = Length.
W = Width.

TABLE 1-4. CLUTTER WEIGHT RANGES

Clutter Type	Weight Range in Grams		
	Small	Medium	Large
Ferrous	10 to 510	511 to 2200	> 2201
Nonferrous	10 to 270	275 to 800	> 801

SECTION 2. SYSTEM UNDER TEST

2.1 DEMONSTRATOR INFORMATION

AMEC in cooperation with 3Dgeophysics (3Dgeo) provided the information in sections 2.1 through 2.6 as part of their Broad Agency Announcement (BAA) proposal (app D, ref 2). This information was edited to change verb tense and to conform to government report guidelines. Section 2.8 contains ATC's comments on the demonstrated system.

2.2 SYSTEM DESCRIPTION

The underwater towed sensor array (fig. 2), designed by 3Dgeophysics, consists of three Geometrics, Inc. model G-882 mini-marine, cesium vapor magnetometers, a digital data recorder, and batteries. The G-882 magnetometers record data with an absolute accuracy of <3 nanoteslas (nT) at a rate of up to 10 Hz. The sensor array is mounted on a platform constructed with thin plastic sheets, plastic structural separators and stainless steel fastening hardware. This platform is towed along the submerged ground surfaces by a small fiberglass boat. The design and construction of the platform allow it to work on land as well as submerged under as much as 15 feet of water. (ATC only evaluated this system in water depths of 8 feet or less.)

Positioning data are obtained using a Navcom Technologies model SF-2050G Differential Global Positioning System (DGPS) equipped with a StarFire differential correction subscription. This provides sub-decimeter positioning accuracy at a rate of up to 5 Hz. The DGPS data fed to both the magnetometer data logger and the navigation and guidance control computer in the tow vessel.

Figure 2. 3Dgeo's sled in the as-tested configuration.

2.3 DEMONSTRATOR'S POINT OF CONTACT (POC) AND ADDRESS

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2.4 DEMONSTRATOR'S SITE SURVEY METHOD

Due to previous demonstration activities at the shallow water testing facility, AMEC could only complete the survey of the calibration lanes, blind grid, and littoral zones. These areas were surveyed (fig. 3) with a systematic progression of passes using a swath of nearly equally spaced lines (unidirectional data collection). The survey lines were created using the navigation and guidance software. Additional data were collected in some areas using a grid of survey lines (bidirectional data collection).

The survey data are downloaded to a laptop computer and copied onto a CD-ROM for backup and archiving at the completion of each day's fieldwork. MagMap2000 and MagPick, magnetics processing software (Geometrics, Inc.), were used to preliminarily process the acquired data and complete a review for quality control purposes. The DGPS positioning data were also reviewed to make certain that data coverage gaps are not prevalent in the data sets.

Figure 3. 3Dgeo surveying in the littoral zone.

2.5 DEMONSTRATOR'S QUALITY CONTROL (QC) AND QUALITY ASSURANCE (QA)

The proposed data collection parameters and survey design were developed to maximize data quality and collection efficiency. The magnetics data were acquired at a rate of up to ten samples/second on each of three fish yielding 30 samples/second. The DGPS positioning data were acquired at a rate of five samples/second. The data collection rates were designed to acquire at a rate of at least two samples/linear foot across the survey areas. The real-time navigation and guidance software, which is integrated with the DGPS, was used to monitor survey-positioning data and ensured that the correct survey geometry was maintained and data gaps were minimized. Position information from the APG test site was correlated with the acquired DGPS data during daily data processing to ensure accurate survey information had been collected. The manufacturer listed the accuracy of the DGPS as <0.1 meter in 99 percent of all data samples. Considering the DGPS positioning accuracy, it was expected that target identification position accuracy of ±0.3 meter was achieved.

The quality of the magnetics data depended upon several factors: properly functioning instrumentation, accurate position control, proper documentation of field activities, good signal-to-noise (S/N) ratio, and utilization of the correct recording parameters. For this project, data quality control was maintained in several ways. All field activities, data recording parameters, and daily test results were recorded in a detailed log maintained by the field crew manager/instrument observer. Daily tests for magnetometer readings and DGPS position repeatability were performed at a calibration point at the site prior to data collection. A magnetometer base station was maintained in a fixed position at the site to record the diurnal variations in the earth's magnetic field. The diurnal variations in the data sets were corrected during data processing.

2.6 DATA PROCESSING DESCRIPTION

a. The following list of digital data processing steps was on the data sets:

(1) Making speed and heading file out of GPS $GPVTG messages.

(2) Cutting data into lines based on speed. Data with speed less than 0.3 knot were removed.

(3) Cutting and smoothing base station data.

(4) Applying base station data to the survey data.

(5) Recomputing individual sensor positions.

(6) Removing linear trend using robust estimate to correct base station drift as well as sensor #3 data direct current (DC) shift in littoral area.

(7) Removing very short lines (result of using VTG messages).

(8) Gridding and smoothing.

b. At the completion of the site survey, all data were formally processed and analyzed using MagMap2000 and MagPick software. The MagPick software contains new UXO detection and discrimination algorithms that were used to analyze the acquired data. MagPick generates estimates of the X, Y, Z position and mass of magnetic anomalies such as UXO. MagPick implements a geophysical inversion technique using maximum likelihood dipole pattern matching methods to analyze anomalies. In this approach the basic nature of the anomaly source is considered to be known (point object or sphere), and then to check the quality of the model, a synthetic magnetic field is calculated from the model and compared with the observed one. UXO targets produce a magnetic field distortion that are approximated with the well-defined fields of magnetic dipoles or uniformly magnetized spheres. The magnetic dipole itself is characterized by six unknown values: X, Y, Z, as coordinates of its center, and Jx, Jy, Jz, which represent values of the magnetic moment. The mathematical inversion task performed by MagPick is summarized as follows: Given magnetic field $T_{observed}$ in the vicinity of the object, the unknown values X, Y, Z, Jx, Jy, and Jz are varied such that the computed field $C_{omputed}$ assumes maximum similarity with the observed field $T_{observed}$.

2.7 DEMONSTRATOR'S SITE PERSONNEL

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2.8 ATC'S SURVEY COMMENTS

The towing vessel used both a gasoline outboard motor at the stern of the boat and two trolling motors, mounted to the port, and starboard sides near the bow, for propulsion, and maneuvering. The outboard motor provided the power needed to tow the sled along the bottom of the pond, while the thrust produced by the trolling motors helped to maneuver the boat into position for the next survey line. The trolling motors also helped counteract some of the wind and wave actions that would otherwise force the boat off the required survey heading. Experimenting using both the forward and reverse thrust from just one trolling motor led to the elimination of the second unit.

The design of the bottom-riding sled allows it to maneuver easily along the contours that form the shoreline and in the open water at the center of the pond. The sled rests on four wheels (two swivel and two fixed) and connects to the boat by means of a rigid pole. The combination of motors on the towing vessel, the rigid pole and swivel wheels allows the sled to make pivot turns. Aerodynamic design elements incorporated into the plastic sandwich body add to the stability and tow ability of the sled in water.

Overall, the design of this system makes it highly maneuverable in a shallow water environment.

SECTION 3. SURVEY COST ANALYSIS

3.1 DATES OF SURVEY

The AMEC/3Dgeo electromagnetic system was tested from 27 through 30 September 2006.

3.2 SITE CONDITIONS

3.2.1 Atmospheric Conditions

An ATC weather station located adjacent to the test site recorded the average temperature and precipitation on an hourly basis for each day of operation. The temperatures listed in Table 3-1 represent the average temperature from 0700 through 1700 hours. The hourly weather logs used to generate this summary are provided in Appendix A.

3.2.2 Water Conditions

Water conditions were monitored using a TIDALITE IV Portable Tide Gauge System®. Data recorded included water depth and temperature, significant wave height based on the average 1/3 wave height seen over the test period using the Draper/Tucker analysis method, and the full-wave frequency calculated by full-wave mean crossing detection. The values displayed in Table 3-1 were averaged from 0700 through 1700 hours. Detailed information is provided in Appendix B.

TABLE 3-1. SITE CONDITION SUMMARY

Date, 06	Air Temperature, °C	Wind, km/hr	Water Temperature, °C	Water Depth, m[a]	Significant Wave Height, m	Wave Frequency, Hz
27 Sept	21.2	9.7	16.8	-0.1	Lost	Lost
28 Sept	22.9	17.5	16.8	-0.05	Lost	Lost
29 Sept	17.2	9.2	16.6	0	Lost	Lost
30 Sept	16.2	4.2	16.6	0	Lost	Lost

[a]Variance between the required 2.4-meter test depth and actual test conditions.
Lost = instrumentation malfunction.

3.3 SURVEY ACTIVITIES

The information contained in this section provides an estimate of the time needed and costs associated with surveying an area with this demonstrator’s system. This includes data on equipment setup and calibration, site survey and any resurvey time, and downtime due to system malfunctions and maintenance requirements.

3.3.1 Survey Times

a. A government representative monitored and recorded all on-site activities, which were grouped into one of 11 categories. The first eight categories were chargeable to the system while the last three were not. Categorizing these activities provided insight into the technical and logistical aspects of the system. The times recorded in each category were then matched with the number of demonstrator personnel, assigned skill levels, and a consistent (across-vendor) salary to produce an estimate of the survey costs.

(1) Initial setup/mobilization. Started at the time the demonstrator's equipment arrived at the survey site and stopped when the system was ready to acquire data.

(2) Daily setup/close-up. Monitored time spent mounting and dismounting the equipment each day.

(3) Instrument calibration. Recorded the amount of time used for daily quality assurance checks (e.g., sensors, GPS data, survey data quality).

(4) Data collection. Time spent surveying the test area.

(5) Downtime (nonsurvey time) for equipment/data checks. Covered time spent troubleshooting equipment or verifying survey tracks.

(6) Downtime (nonsurvey time) for equipment failure. Examples include replacing damaged cables, lost communication with base station, and any other failure that prevented surveying. Some weather-related failures fall into this category, for example, light-emitting diode (LED) displays darkened by the sun, wind creating waves too high to permit surveying, etc.

(7) Downtime (nonsurvey time) for maintenance. Battery replacement and memory downloads are typical examples.

(8) Demobilization. Commenced once the demonstrator completed the survey and concluded the final on-site check of the test data and ended when the equipment and personnel were ready to leave the site.

(9) Nonchargeable downtime for breaks and lunch. The demonstrator's company policy set this standard.

(10) Nonchargeable downtime for weather-related causes (i.e., lighting, high wet-bulb heat index, and similar events).

(11) Nonchargeable downtime due to ATC range operating requirements. Danger zone conflicts, lack of support personnel, equipment or other ATC-caused delays.

b. The daily log sheets are provided in Appendix B. Summarized information pertaining to the operational, maintenance, and logistic aspects of the system is provided in Table 3-2.

TABLE 3-2. TIME ON-SITE

Date (2006)	**27 Sept**	**28 Sept**	**29 Sept**	**30 Sept**	**Activity totals, hr**
Activity (daily times recorded in minutes)					
Initial setup	250	95			5.7
Daily setup/close-up	10	30	45	45	2.2
Instrumentation calibration		40			0.7
Data collection		315	265	285	14.4
Equipment/data checks					
Equipment failure		20	210		3.8
Maintenance		10	25		0.6
Demobilization				135	2.3
Breaks/lunch					
Weather-related					
ATC downtime	55				
Daily total, hr	5.3	8.4	9.1	7.8	

Note: Task times rounded to 5-minute increments.

3.3.2 On-Site Data Collection Costs

The times associated with the 11 activities have been grouped into the three basic components of the evaluation: initial setup, site survey, and pack-up (demobilization). Note that site survey time includes daily setup/stop time, collecting data, breaks/lunch, downtime for equipment/data checks or maintenance, downtime due to failure, and downtime due to weather. This combines the actual survey cost with the demonstrator's associated on-site overhead costs.

A standardized estimate for labor costs associated with this effort was then calculated using the following job categories: supervisor ($95.00/hr), data analyst ($57.00/hr), and site support ($28.50/hr). The estimated costs are presented in Table 3-3.

TABLE 3-3. CALCULATED SURVEY COSTS

	No. of Persons	Hourly Wage	Hours	Cost
Initial Setup				
Supervisor	1	$95.00	5.7	$541.50
Data analyst	1	$57.00	5.7	$324.90
Site support	2	$28.50	5.7	$324.90
Subtotal				**$1191.30**
Site Survey				
Supervisor	1	$95.00	21.7	$2061.50
Data analyst	1	$57.00	21.7	$1236.90
Site support	2	$28.50	21.7	$1236.90
Subtotal				**$4535.30**
Demobilization				
Supervisor	1	$95.00	2.3	$218.50
Data analyst	1	$57.00	2.3	$131.10
Site support	2	$28.50	2.3	$131.10
Subtotal				$480.70
Total on-site costs				**$6207.30**

3.4 COST ANALYSIS

The data collection process described above provided an on-site cost guide to compare the performance of this vendor with any other that has demonstrated at the shallow water site. It is not a true indicator of survey costs. Many other expenses have not been included, such as travel costs, per diem, off-site data processing and analysis, company overhead, and profit.

Calculating the area surveyed was done by plotting the raw GPS coordinates and then combining the sensor swath (line spacing and associated overlap).

To determine the number of acres surveyed per day, the total number of hours spent at the test site (table 3-2) was divided by 8 (converts to 8-hr days). The number of acres was then divided by the number of 8-hour days. The cost per acre was determined by dividing the total survey costs (table 3-3) by the same number of acres. This information is summarized in Table 3-4.

TABLE 3-4. SURVEY COSTS

Area surveyed (acre[a])	2.8
Time on-site (8-hr days)	4.15
Calculated survey cost (U.S. dollars)	$6207.30
Acres per day	0.67
Cost per acre	$2216.89

[a]Acre = 4047 m^2.

A comparison of AMEC/3Dgeo's survey costs with the EQT-ORD criteria is presented in Table 3-5.

TABLE 3-5. TEST RESULTS - CRITERIA COMPARISON

Metric	Threshold	Objective	AMEC/3Dgeo
Cost rate	$4000 per acre	$2000 per acre	$2216.89
Production rate	5 acres per day	50 acres per day	0.67

SECTION 4. TECHNICAL PERFORMANCE RESULTS

4.1 AREA SURVEYED

4.1.1 Calculated Area

Both the test and scoring methodologies required the demonstrator to survey 100 percent of each of the four test areas (blind grid, open water, littoral, and deeper water). Scoring a partially surveyed area alters the ordnance and clutter sample sizes, test area boundaries, and decreases the statistical confidence in the performance statements made for that area. Allowing partial scoring decreases the validity of performance comparisons made between multiple test areas for a single demonstrator and comparisons made between multiple demonstrators for a single test area.

Realizing that some systems may not be able to survey 100 percent of a given test area, a ranking system was established. The percent coverage for a given test area is determined by first plotting the raw GPS coordinates combined with the sensor swath (line spacing and associated overlap), calculating the area surveyed, and then comparing the surveyed area with the total test area.

$$\frac{\text{Section Surveyed}}{\text{Test Area Size}} \times 100 = \%\ \text{Surveyed}$$

The demonstrator's system is always scored against the complete ground truth for a given test area regardless of the percentage covered.

4.1.2 Area Assessment

The ranking system and survey results are presented in Table 4-1.

TABLE 4.1. M882 SURVEY RANKING SYSTEM AND RESULTS

Ranking System		**Survey Results**		**Data Use**
% Area Covered	**Ranking**	**Test Area**	**% Area Covered**	
95 to 100	Met	Blind grid	100	Direct comparison between systems and areas.
90 to 94	Generally met			Comparison between systems and areas. A small negative bias is contained in the reported numbers (bias not quantified in this report).

TABLE 4.1. (CONT'D)

Ranking System		Survey Results		Data Use
% Area Covered	**Ranking**	**Test Area**	**% Area Covered**	
50 to 89	Partially met	Littoral	80	Reported, not compared between systems or areas. A large negative bias is contained in the reported numbers (bias not quantified in this report).
0 to 49	Not met			Not scored/not reported.

Two of the four test areas within the shallow water site were damaged during a prior demonstration. An undetermined percentage of projectiles in the open- and deeper-water areas that were either pressed flush with or resting on top of the pond bottom have been dislodged and dragged out of their original locations. Accurately measuring system performance in these areas is not possible. The scope of this demonstration was reduced to the blind grid and littoral test areas only.

4.2 SYSTEM SCORING PROCEDURES

a. The scoring entities used in this program are predicated on knowing the composition and location of every detectable item in an area. The deeper water area is the one exception. Ground truth targets were placed in this area without a presurvey and clearing operation. Therefore, only the system's probability of detection (P_d) was evaluated in this area.

b. The best indicator of survey performance is the blind grid. This area provides a statically valid, controlled environment in which the demonstrator must provide a response (ordnance, clutter, or blank) at each of the 644 locations. Comparison of the response and discrimination lists to the ground truth in this area both determines the range of ordnance the system can reliably detect and establishes the baseline to which system performance in all other test areas is measured.

c. The scoring terms and definitions, along with an explanation of the receiver operating characteristics (ROC) curve development and the chi-square analysis used in this report, are provided in Appendix C.

d. Demonstrator performance was scored in two stages: response and discrimination.

e. Response stage scoring evaluates the ability of the demonstrator's system to detect emplaced ground truth targets without regard to discriminating ordnance from clutter. In this stage, the GPS locations and signal strengths of all anomalies the demonstrator deemed sufficient for further investigation and/or processing are reported. This list was generated with minimal processing, i.e., associating signal strength with GPS location, and includes only signals that are above the system noise level.

f. The discrimination stage evaluated the demonstrator's ability to segregate ordnance from clutter. The same GPS locations reported in the response stage anomaly list were evaluated on the basis of the demonstrator's discrimination process (section 2.6). A discrimination stage list was generated and prioritized on the basis of the demonstrator's determination that an anomaly was more likely to be ordnance rather than clutter. Typically, higher output values indicate a higher confidence that an ordnance item is present at a specified location. The demonstrator then specifies the threshold value for the prioritized ranking that provides optimal system performance. This value is the discrimination stage threshold.

g. Both the response and discrimination lists contain the identical number of potential target locations, differing only in the priority ranking of the declarations.

h. Within both of these stages, the following entities were measured:

(1) P_d.

(2) Probability of false positive (P_{fp}).

(3) Probability of background alarm (P_{ba})/background alarm rate (BAR).

4.2.1 <u>ROC Curves</u>

a. Based on the entire range of ground truth targets used at this site, ROC curves were generated for both the response and discrimination stages. In both stages, the probability of detection versus false alarm rates was plotted. False alarms were divided into two groups: (1) anomalies corresponding to emplaced clutter items, thereby measuring the P_{fp}, and (2) anomalies not corresponding to any known item, termed background alarms (P_{ba}) in the blind grid area and BAR in all other areas.

b. The ROC curves for the response and discrimination stages for all areas surveyed are shown in Figures 4 through 7. Horizontal lines illustrate the system performance at the demonstrator's recommended noise level during the response stage or discrimination threshold level in the discrimination stage. The point where the curve crosses the horizontal line defines the subset of targets the demonstrator recommends digging.

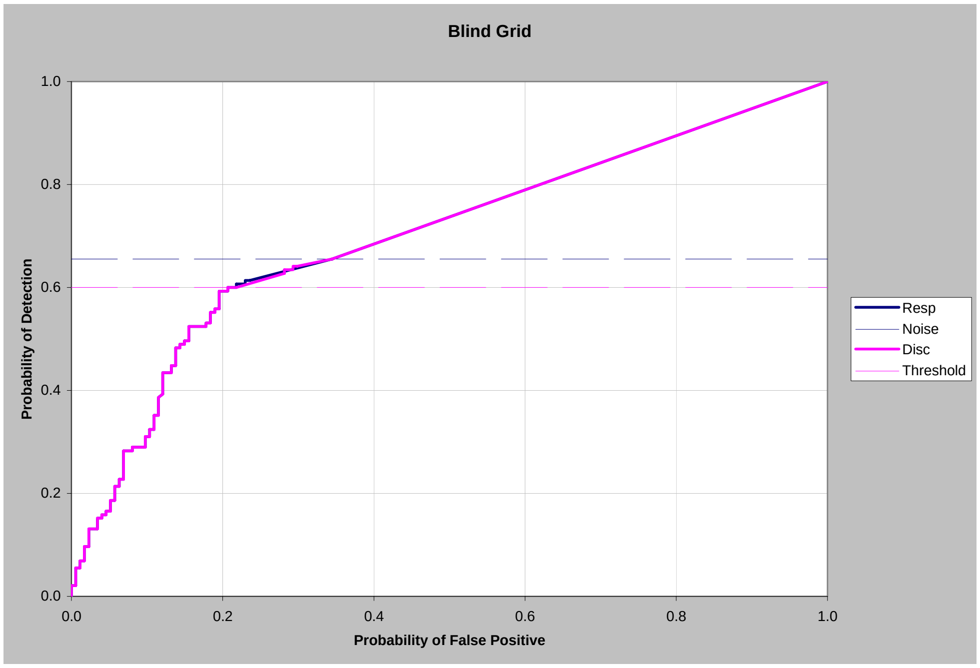

Figure 4. Blind grid P_d versus P_{fp}.

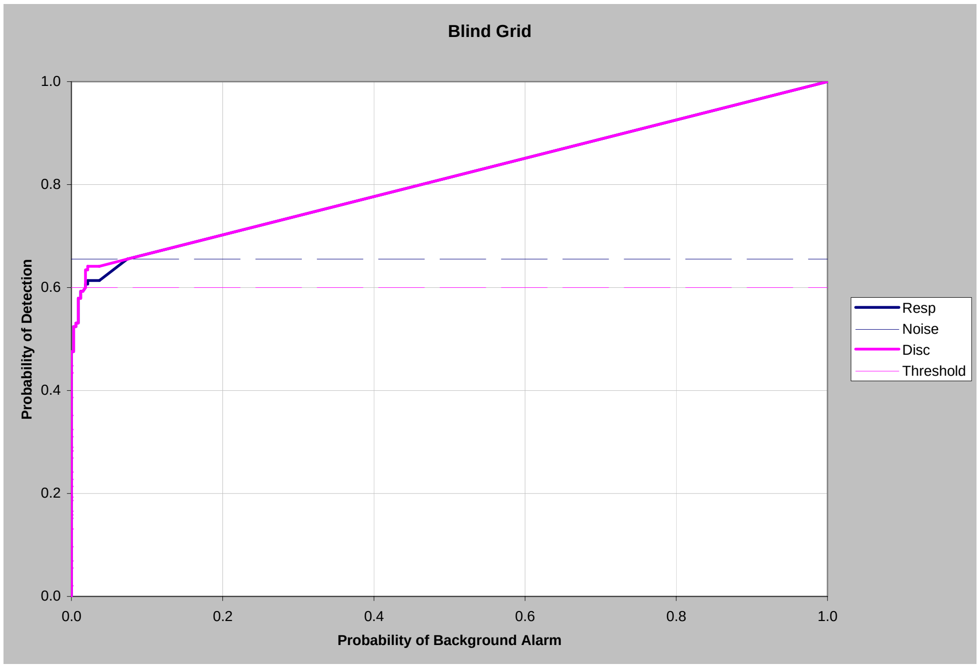

Figure 5. Blind grid P_d versus P_{ba}.

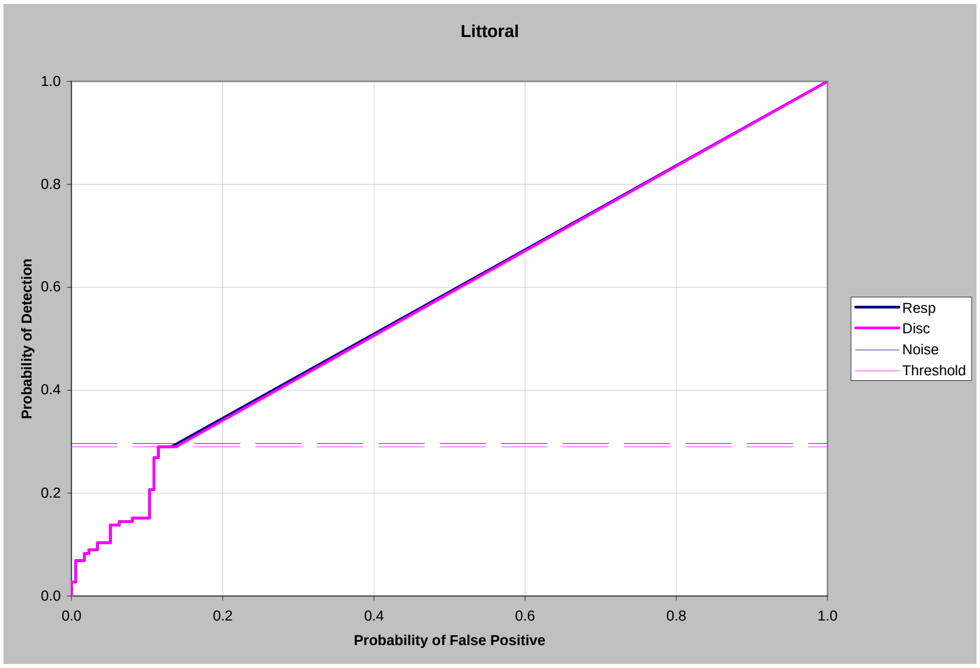

Figure 6. Littoral P_d versus P_{fp}.

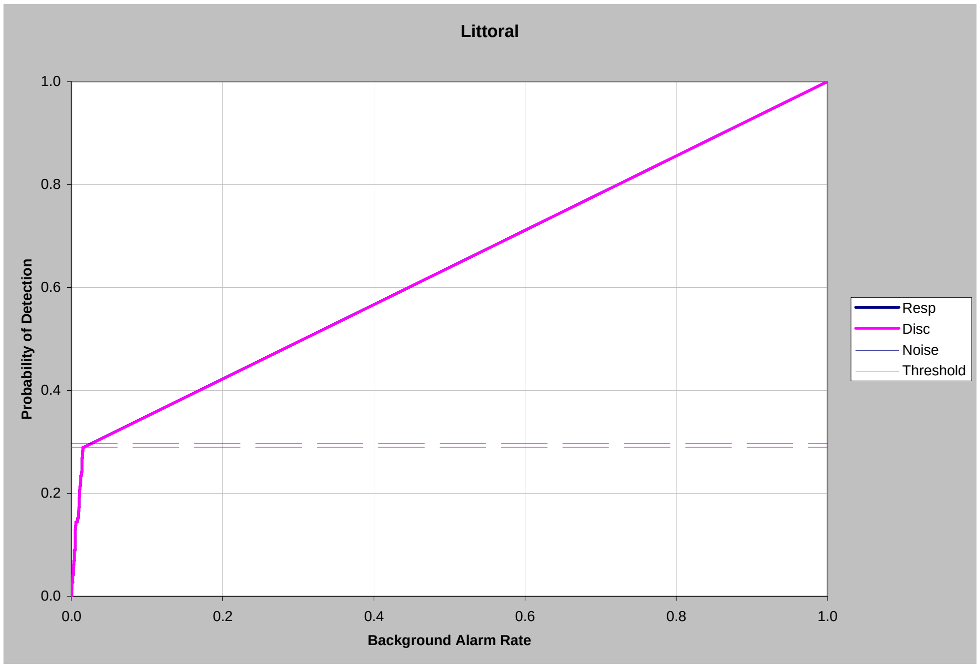

Figure 7. Littoral P_d versus BAR.

4.2.2 Detection Results

Detection results, broken out by stage, area surveyed, and ordnance size, are presented in Table 4-2. The results by size indicate how well the demonstrator detected/discriminated ordnance of a given caliber. Overall results summarize ordnance detection over a given area. All values were calculated assuming the number of detections was a binomially distributed random variable. These results are reported at the 90 percent reliability/95 percent confidence levels unless otherwise noted.

TABLE 4-2. SYSTEM DETECTION SUMMARY

Metric	Overall	By Projectile Caliber				
		40 mm	60 mm	81 mm	105 mm	155 mm
Blind grid						
Response stage						
P_d	65.5%	51.7%	31.0%	55.2%	89.7%	100.0%
P_d lower 90% confidence	60.0%	38.4%	19.7%	41.7%	78.4%	92.4%
P_{fp}	34.5%					
P_{fp} lower 90% confidence	29.7%					
P_{ba}	7.4%					
Discrimination stage						
P_d	60.0%	51.7%	17.2%	55.2%	86.2%	89.7%
P_d lower 90% confidence	54.4%	38.4%	8.6%	41.7%	74.3%	78.4%
P_{fp}	21.8%					
P_{fp} lower 90% confidence	17.8%					
P_{ba}	1.8%					
Littoral region						
Response stage						
P_d	29.7%	34.5%	6.9%	31.0%	24.1%	51.7%
P_d lower 90% confidence	24.7%	22.6%	1.8%	19.7%	14.0%	38.4%
P_{fp}	14.4%					
P_{fp} lower 90% confidence	11.0%					
BAR m^{-2}	0.019					
Discrimination stage						
P_d	29.0%	34.5%	6.9%	27.6%	24.1%	51.7%
P_d lower 90% confidence	24.0%	22.6%	1.8%	16.8%	14.0%	38.4%
P_{fp}	13.2%					
P_{fp} lower 90% confidence	10.0%					
BAR m^{-2}	0.016					
Response stage noise level: 0.09						
Recommended discrimination threshold: 3.6						

4.2.3 System Discrimination

By using the demonstrator's recommended setting, the items detected and correctly classified as ordnance (fig. 8) were further evaluated as to whether the demonstrator could correctly identify the ordnance type. The list of ground truth ordnance items was provided to the demonstrator prior to testing.

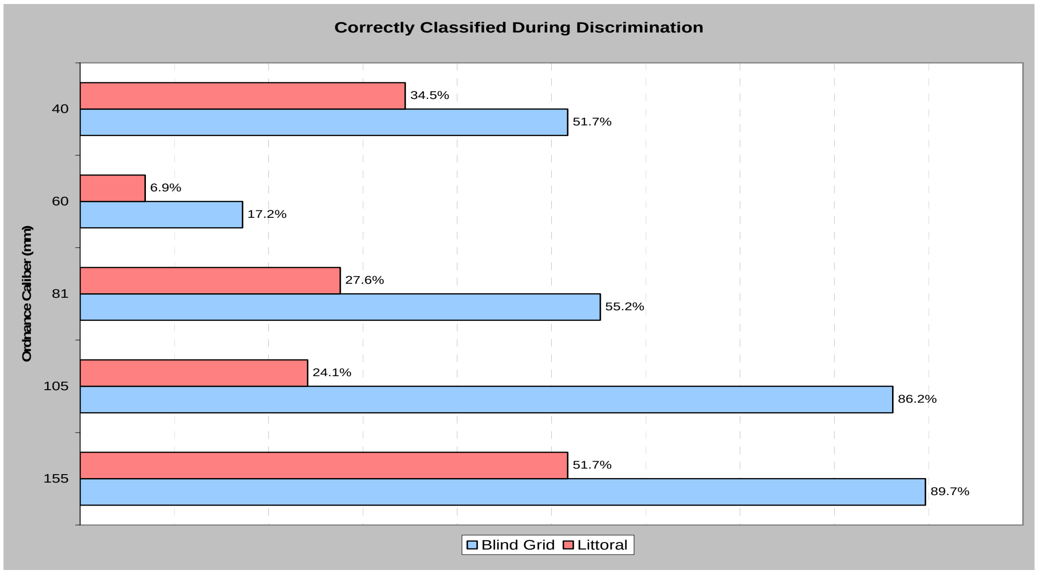

Figure 8. Percent of ordnance correctly classified during the discrimination stage.

4.2.4 System Effectiveness

Efficiency and rejection rates were calculated to quantify the discrimination ability at two specific points of interest on the ROC curve: the point where no decrease in P_d occurred (i.e., the efficiency is by definition equal to one) and the operator-selected threshold. These values are presented in Table 4-3.

TABLE 4-3. EFFICIENCY AND REJECTION RATES

	Efficiency	**False Positive Rejection Rate**	**Background Alarm Rejection Rate**
Blind Grid			
At operating point	0.92	0.37	0.75
With no loss of P_d	1.00	0.13	0.50
Littoral Region			
At operating point	0.98	0.08	0.14
With no loss of P_d	1.00	0.04	0.11

4.2.5 Chi-Square Analysis

Typically, this report contains a chi-square 2-by-2 contingency test for comparison between ratios used to compare performance across test areas with regard to P_d^{res}, P_d^{disc}, P_{fp}^{res}, and P_{fp}^{disc}, efficiency, and false alarm rejection rates. The intent of the comparison is to determine if the features introduced in each test region have a degrading effect on the performance of the sensor system.

This system did not survey enough of the littoral test areas to permit a valid comparison of performance with the blind grid area.

4.2.6 Location Accuracy

The data points in the scatter graph in Figure 9 represent the coordinates of ordnance items in the littoral test area that were first detected in the response stage within a 0.5-meter radius of their true positions, then correctly identified as ordnance in the discrimination stage. The maximum error represents the 0.5-meter detection limit. The mean error represents the statistical mean of the sample considered.

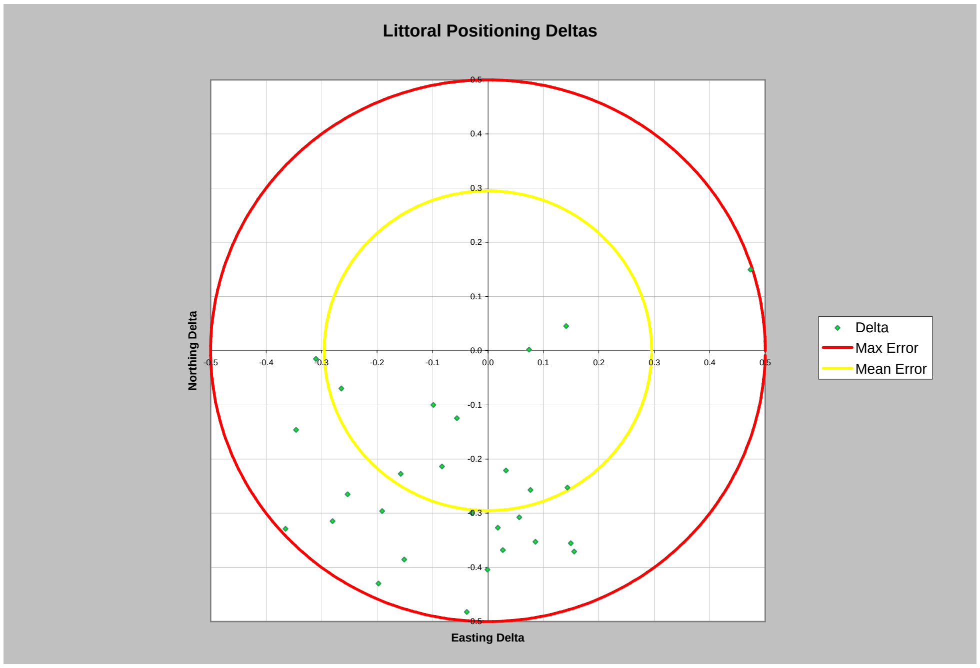

Figure 9. Littoral zone positioning error scatter graph.

A visual analysis of the data point distribution shows the majority of points in quadrant III with a smaller number in quadrant IV. This suggests that there is a positioning bias in the system.

Comparisons between the results obtained during testing and the EQT-ORD criteria are presented in Table 4-4.

TABLE 4-4. AMEC/3Dgeo TEST RESULTS - CRITERIA COMPARISON

Metric	**Threshold**	**Objective**	**By Area**	
Detection	80% ordnance items buried to 1 foot and under 8 feet (2.4 m) of water.	95% ordnance items buried to 4 feet and under 8 feet (2.4 m) of water.	Blind grid	65.5%
			Littoral	29.7%
Discrimination	Rejection rate of 50% of emplaced non-UXO clutter.	Rejection rate of 90% of emplaced non-UXO clutter.	Blind grid	37%
			Littoral	8%
	Maximum false negative rate of 10%.	Maximum false-negative rate of 0.5%.	Not assessed. An analytical procedure is not available to address this criterion.	
Reacquisition	Reacquire within 1 meter.	Reacquire within 0.5 meter.	The reported detection values are based on ordnance items identified within 0.5 meter of the georeferenced ground truth targets.	

Note: The blind grid and open water areas are in general accordance with the threshold requirements.

SECTION 5.   APPENDIXES

APPENDIX A. TEST CONDITIONS LOG

ATMOSPHERIC CONDITIONS

Date, 06	Time, EDT	Average Wind Direction, deg	Average Wind Speed, km/hr	Wind Direction Average Standard Deviation, deg	Peak Wind Speed, km/hr	Average Temperature, °C
27 Sept	0700	51	0.7	12	2.2	14.4
	0800	159	4.7	21	9.7	18.0
	0900	202	8.6	17	13.0	20.3
	1000	208	9.4	20	15.8	21.4
	1100	203	11.2	16	18.4	22.3
	1200	196	15.1	12	21.6	23.1
	1300	194	15.5	10	21.6	23.3
	1400	200	14.4	11	20.5	23.3
	1500	205	11.2	10	16.9	23.3
	1600	204	10.1	9	13.7	22.9
	1700	184	5.8	4	9.0	21.1
28 Sept	0700	166	6.8	17	13.0	17.5
	0800	171	9.0	17	17.3	19.6
	0900	175	15.1	14	23.8	21.3
	1000	173	16.2	16	28.4	22.9
	1100	178	19.1	13	29.5	24.2
	1200	186	20.5	13	32.0	25.0
	1300	188	22.7	12	32.4	25.1
	1400	188	22.7	12	33.8	25.0
	1500	180	19.8	11	32.8	24.7
	1600	174	20.9	14	34.2	24.0
	1700	175	20.2	13	35.3	22.8
29 Sept	0700	295	8.6	25	20.2	13.1
	0800	307	9.4	24	18.7	14.9
	0900	310	9.0	27	18.7	16.2
	1000	314	10.1	26	23.0	16.8
	1100	304	9.4	26	22.3	17.8
	1200	300	11.5	24	24.1	18.6
	1300	300	11.2	28	23.0	18.8
	1400	300	9.7	26	20.2	18.9
	1500	294	7.9	25	17.3	18.6
	1600	292	9.0	23	19.8	18.4
	1700	312	5.4	25	12.6	17.6
30 Sept	0700	34	2.2	16	5.0	10.1
	0800	66	4.3	22	9.0	13.2
	0900	121	4.3	44	10.8	15.5
	1000	161	2.2	23	6.1	15.8
	1100	80	3.6	23	6.8	15.2
	1200	77	4.7	27	9.4	17.2
	1300	110	4.0	40	10.1	18.4
	1400	217	7.2	12	12.2	18.3
	1500	230	8.6	12	13.3	18.8

The TIDALITE IV Portable Tide Gauge System® is not operational. Manual water depth and temperature measurements were recorded each morning. The single measurements for each day are shown in Table 3.1.

APPENDIX B. DAILY ACTIVITIES LOG

Company: AMEC/3Dgeo Date: 27 September 2006			On-site Personnel: Nathan Eklund, Brian Herridge, Erik Kitt	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
1045	1140	Arrived at site ATC safety briefing.	Downtime ATC	55
1140	1450	Sled with magnetometers attached is assembled.	Initial setup	190
1450	1550	Began assembling equipment on boat; power supplies and distribution.	Initial setup	60
1550	1600	Covering equipment for the night.	Daily close-up	10

Company: AMEC/3Dgeo Date: 28 September 2006			On-site Personnel: Nathan Eklund, Brian Herridge, Erik Kitt	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0755	0930	Arrived at site. Still initial setup. Plan is to set up GPS, fill ballast bags, and configure the boat.	Initial setup	95
0930	1010	Boat in the water, running system checks.	Calibration	40
1010	1235	Began survey of the blind grid.	Collecting data	145
1235	1245	Returned to dock. Added screws to help secure the trolling motor to the boat.	Downtime equipment	10
1245	1450	Surveying.	Collecting data	125
1450	1510	Returned to the dock. Making cables to recharge the trolling motor battery using the outboard motor.	Downtime equipment	20
1510	1635	Surveying.	Collecting data	45
1635	1705	Clean up. Surveying rig left in tack. Covered components with plastic in anticipation of rain overnight.	Daily close-up	30

Company: AMEC/3Dgeo Date: 29 September 2006			**On-site Personnel: Brian Herridge, Erik Kitt**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0750	0805	Arrived at site. Began charging batteries. Drying out equipment from last night's rain.	Daily setup	15
0805	1005	Discovered all batteries had been drained – cause unknown. Reinstalling batteries and reconnecting instrumentation and motors.	Downtime equipment	120
1005	1300	Surveying.	Collecting data	175
1300	1425	The battery for the trolling motor was drawn down too low to operate the motor. Stopped to eat lunch and charge the battery – using the truck instead of the trickle charger.	Downtime equipment	85
1425	1450	Surveying.	Collecting data	25
1450	1455	Returned to dock to refuel the on-board gas generator (using to charge motor battery).	Downtime equipment	5
1455	1510	Began survey of littoral zone.	Collecting data	15
1510	1535	Maneuverability problems. Pulled sled from water to investigate. Vegetation had covered the steel guide wires that support the mast for the GPS antenna. Removed vegetation.	Equipment maintenance	25
1535	1625	Surveying.	Collecting data	50
1625	1655	Close-up.	Daily close-up	30

Company: AMEC/3Dgeo Date: 30 September 2006			**On-site Personnel: Nathan Eklund, Brian Herridge, Erik Kitt**	
Start	**Stop**	**Remarks**	**Activity**	**Chargeable**
0810	0840	Setup.	Daily setup	30
0840	1325	Survey.	Collecting data	285
1325	1345	Demonstration of the sled's maneuverability at higher-than-survey speeds.	Nonchargeable downtime	20
1345	1600	Demobilization.	Demobilization	135

APPENDIX C. TERMS AND DEFINITIONS

GENERAL DEFINITIONS

Anomaly: Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

Detection: An anomaly location that is within R_{halo} of an emplaced ordnance item.

Munitions and Explosives Of Concern (MEC): Specific categories of military munitions that may pose unique explosive safety risks, including UXO as defined in 10 USC 101(e)(5), DMM as defined in 10 USC 2710(e)(2) and/or munitions constituents (e.g. TNT, RDX) as defined in 10 USC 2710(e)(3) that are present in high enough concentrations to pose an explosive hazard.

Emplaced Ordnance: An ordnance item buried by the government at a specified location in the test site.

Emplaced Clutter: A clutter item (i.e., non-ordnance item) buried by the government at a specified location in the test site.

R_{halo}: A pre-determined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. For the purpose of this program, a circular halo 0.5 meters in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meters in length. When ordnance items are longer than 0.6 meters, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the projected length of the ordnance onto the ground plane plus 1 meter.

Response Stage Noise Level: The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the Blind Grid test area.

Discrimination Stage Threshold: The demonstrator selects the threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

Binomially Distributed Random Variable: A random variable of the type which has only two possible outcomes, say success and failure, is repeated for n independent trials with the probability p of success and the probability 1-p of failure being the same for each trial. The number of successes x observed in the n trials is an estimate of p and is considered to be a binomially distributed random variable.

RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection (P_d^{res}): P_d^{res} = (No. of response-stage detections)/(No. of emplaced ordnance in the test site).

Response Stage False Positive (fp^{res}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Response Stage Probability of False Positive (P_{fp}^{res}): P_{fp}^{res} = (No. of response-stage false positives)/(No. of emplaced clutter items).

Response Stage Background Alarm: An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open water or littoral scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm (P_{ba}^{res}): Blind Grid only: P_{ba}^{res} = (No. of response-stage background alarms)/(No. of empty grid locations).

Response Stage Background Alarm Rate (BAR^{res}): Open water only: BAR^{res} = (No. of response-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{res}, P_{fp}^{res}, P_{ba}^{res}, and BAR^{res} are functions of t^{res}, the threshold applied to the response-stage signal strength. These quantities can, therefore, be written as $P_d^{res}(t^{res})$, $P_{fp}^{res}(t^{res})$, $P_{ba}^{res}(t^{res})$, and $BAR^{res}(t^{res})$.

DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to non-ordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection (P_d^{disc}): P_d^{disc} = (No. of discrimination-stage detections)/(No. of emplaced ordnance in the test site).

Discrimination Stage False Positive (fp^{disc}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Discrimination Stage Probability of False Positive (P_{fp}^{disc}): P_{fp}^{disc} = (No. of discrimination stage false positives)/(No. of emplaced clutter items).

Discrimination Stage Background Alarm: An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open water or littoral scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm (P_{ba}^{disc}): P_{ba}^{disc} = (No. of discrimination-stage background alarms)/(No. of empty grid locations).

Discrimination Stage Background Alarm Rate (BAR^{disc}): BAR^{disc} = (No. of discrimination-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{disc}, P_{fp}^{disc}, P_{ba}^{disc}, and BAR^{disc} are functions of t^{disc}, the threshold applied to the discrimination-stage signal strength. These quantities can, therefore, be written as $P_d^{disc}(t^{disc})$, $P_{fp}^{disc}(t^{disc})$, $P_{ba}^{disc}(t^{disc})$, and $BAR^{disc}(t^{disc})$.

RECEIVER-OPERATING CHARACERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed based on the above definitions. The ROC curves plot the relationship between P_d versus P_{fp} and P_d versus BAR or P_{ba} as the threshold applied to the signal strength is varied from its minimum (t_{min}) to its maximum (t_{max}) value.[1] Figure A-1 shows how P_d versus P_{fp} and P_d versus BAR are combined into ROC curves. Note that the "res" and "disc" superscripts have been suppressed from all the variables for clarity.

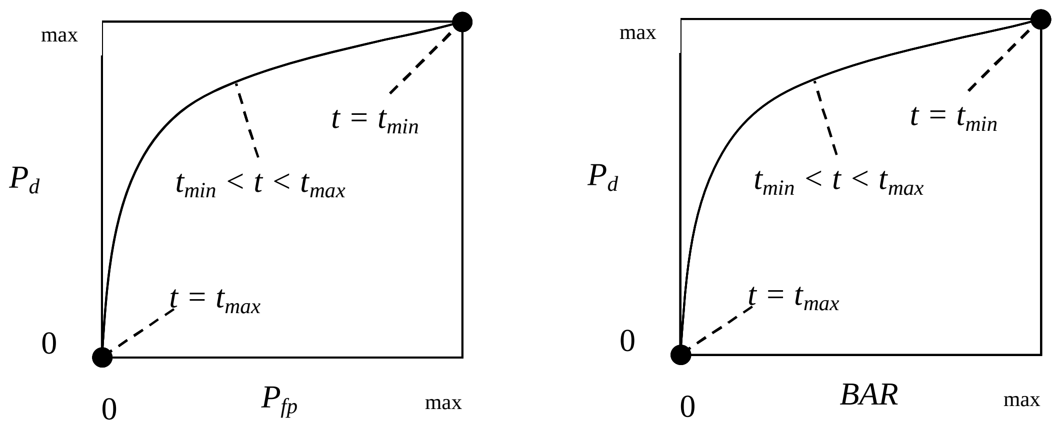

Figure A-1. ROC curves for open-site testing. Each curve applies to both the response and discrimination stages.

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[1]Strictly speaking, ROC curves plot the P_d versus P_{ba} over a predetermined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an Open Water scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the Open Water ROC curves do not have information from low signal-output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the Blind Grid test sites are true ROC curves.

METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E): $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$: measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage t_{min}) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

False Positive Rejection Rate (R_{fp}): $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$: measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage t_{min}). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate (R_{ba}):

Blind Grid: $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$
Open water: $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})])$

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

CHI-SQUARE COMPARISON EXPLANATION:

The Chi-square test for differences in probabilities (or 2 x 2 contingency table) is used to analyze two samples drawn from two different populations to see if both populations have the same or different proportions of elements in a certain category. More specifically, two random samples are drawn, one from each population, to test the null hypothesis that the probability of event A (some specified event) is the same for both populations (ref 3, pages 144 through 151).

A one-sided 2 x 2 contingency table is used in the Shallow Water Site Program to compare each area (Open Water, Littoral, Deep Water) to the Blind Grid since each area introduces a water feature that makes it potentially more difficult to survey than the Blind Grid. The one-sided 2 x 2 contingency table is used to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly degraded by the more challenging feature introduced. A two-sided 2 x 2 contingency table is used to compare performance between any two of the test sites other than the Blind Grid, to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly different between those two test sites.

The test statistic of the 2 x 2 contingency table is the Chi-square distribution with one degree of freedom. For the one-sided test, a significance level of 0.05 is chosen which sets a critical decision limit of 3.84 from the Chi-square distribution with one degree of freedom. It is a critical decision limit because if the test statistic calculated from the data exceeds this value, the two proportions tested will be considered significantly different. If the test statistic calculated from the data is less than this value, the two proportions tested will be considered not significantly different.

An exception must be applied when either a 0 or 100 percent success rate occurs in the sample data. The Chi-square test cannot be used in these instances. Instead, Fischer's Exact Test is used and the critical decision limit is the chosen significance level, which is 0.05 for one-sided tests and 0.10 for two-sided tests. With Fischer's test, if the test statistic (p-value) is less than the critical value, then the null hypothesis of similar performance is rejected in favor of the alternative hypothesis: significantly greater than for the one-sided case or significantly different for the two-sided case.

Shallow-water UXO Detection Test Site examples, where blind grid results are compared to those from the open water and littoral sites and the non-grid sites (open water and littoral) are compared to each other as follows. It should be noted that a significant result does not prove a cause and effect relationship exists between the change in survey area and sensor performance; however, it does serve as a tool to indicate that one data set reflects relatively degraded system performance of a large enough scale than can be accounted for merely by chance or random variation. Note also that a result that is not significant indicates that there is not enough evidence to declare that anything more than chance or random variation within the same population is at work between the two data sets being compared.

Demonstrator X achieves the following overall results after surveying each of the three areas using the same system (results indicate the number of ordnance detected divided by the number of ordnance emplaced):

	Blind Grid	Open water	Littoral
P_d^{res}	100/100 = 1.0	8/10 = .80	20/33 = .61
P_d^{disc}	80/100 = 0.80	6/10 = .60	8/33 = .24

P_d^{res}: BLIND GRID versus OPEN WATER. Using the example data above to compare probabilities of detection in the response stage, all 100 ordnance out of 100 emplaced ordnance items were detected in the blind grid while 8 ordnance out of 10 emplaced were detected in the open water. Fischer's test must be used since a 100 percent success rate occurs in the data. Fischer's test uses the four input values to calculate a test statistic (p-value) of 0.0075 that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.80) is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the detection ability of demonstrator X's system seems to have been degraded in the open water relative to results from the blind grid using the same system.

P_d^{disc}: BLIND GRID versus OPEN WATER. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 emplaced ordnance items were correctly discriminated as ordnance in blind grid testing while 6 out of 10 emplaced ordnance items were correctly discriminated as such in open water testing. Those four values are used in the Chi-square Contingency Test to calculate a test statistic of 1.12. Since the test statistic is less than the critical value of 3.84, the two discrimination stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{res}: BLIND GRID versus LITTORAL. Using the example data above to compare probabilities of detection in the response stage, 100 out of 100 and 20 out of 33 are used to calculate a test statistic (< 0.000) that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.61) is considered to be significantly less at the 0.05 level of significance.

P_d^{disc}: BLIND GRID versus LITTORAL. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 and 8 out of 33 emplaced ordnance items were correctly discriminated as such in open water testing. Those four values are used to calculate a test statistic of 32.01. Since the test statistic is greater than the critical value of 3.84, the smaller discrimination stage detection rate (0.24) is considered to be significantly less at the 0.05 level of significance.

P_d^{res}: OPEN WATER versus LITTORAL. Using the example data above to compare probabilities of detection in the response stage, 8 out of 10 and 20 out of 33 are used to calculate a test statistic of 0.56. Since the test statistic is less than the critical value of 2.71, the two response stage detection rates are considered to be not significantly different at the 0.10 level of significance.

P_d^{disc}: OPEN WATER versus LITTORAL. Using the example data above to compare probabilities of detection in the discrimination stage, 6 out of 10 and 8 out of 33 are used to calculate a test statistic of 2.98. Since the test statistic is greater than the critical value of 2.71, the two discrimination stage detection rates are considered to be significantly different at the 0.10 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and change in performance, it does indicate that the ability of Demonstrator X to correctly discriminate seems to have been degraded by features of the littoral area relative to results from the open water using the same system.

APPENDIX D. REFERENCES

1. Environmental Quality Technology - Operational Requirements Document (EQT-ORD) for: A(1.6.a): UXO Screening, Detection and Discrimination.

2. APG Standardized UXO Technology Shallow Water Demonstration Site Proposal (Technical/Management (Plan). Submitted in response to BAA W91ZLK-04-R-0001, by AMEC Earth and Environmental, Inc., 31 August 2005.

3. Practical Nonparametric Statistics, W.J. Conover, John Wiley & Sons, 1980, pages 144 through 151.

APPENDIX E. ABBREVIATIONS

ADST	=	Aberdeen Data Services Team
APG	=	Aberdeen Proving Ground
ATC	=	U.S. Army Aberdeen Test Center
BAA	=	Broad Agency Announcement
BAR	=	background alarm rate
DC	=	direct current
DGPS	=	Differential Global Positioning System
DMM	=	discarded military munitions
EQT	=	Army Environmental Quality Technology Program
EQT-ORD	=	Environmental Quality Technology - Operational Requirements Document
ERDC	=	U.S. Army Corps of Engineers Engineering, Research and Development Center
ESTCP	=	Environmental Security Technology Certification Program
GPS	=	Global Positioning System
LED	=	light-emitting diode
MEC	=	munitions and explosives of concern
METDC	=	Military Environmental Technology Demonstration Center
P_{ba}	=	probability of background alarm rate
P_d	=	probability of detection
P_d^{disc}	=	probability of detection, discrimination stage
P_d^{res}	=	probability of detection, response stage
P_{fp}	=	probability of false positive
P_{fp}^{disc}	=	probability of false positive, discrimination stage
P_{fp}^{res}	=	probability of false positive, response stage
POC	=	point of contact
QA	=	quality assurance
QC	=	quality control
ROC	=	receiver operating characteristics
SERDP	=	Strategic Environmental Research and Development Program
S/N	=	signal-to-noise
USAEC	=	U.S. Army Environmental Command
UXO	=	unexploded ordnance

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